

LCA Case Studies

LCA of Cleaning and Degreasing Agents in the Metal Industry*

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Abstract

An LCA of cleaning and degreasing agents in the metal industry was carried out. A comparison was made between a solvent product (VOC: a mixture of dearomatised hydrocarbons) and two products derived from vegetable oils (VOFA: rapeseed methyl ester and ethylhexyl laurate derived from coconut oil). The comparison was based on 1000 kg of used product. Results from the inventory and characterisation show that VOFA are environmentally favourable on aspects related to their low volatility and their use of renewable resources. However, they are less favourable on aspects predominantly related to cultivation of the crops. The environmental favourability of VOFA compared to VOC is strongly dependent upon the amounts needed for the task to be performed. Incorporation of data from practical experience concerning the use and waste treatment of VOFA in the metal industry may possibly further improve the environmental profile of VOFA.

Keywords: Cleaning and degreasing agents, metal industry, LCA; coconut oil, ethylhexyl laurate, cleaning and degreasing agents, LCA; ethylhexyl laurate, cleaning and degreasing agents, LCA; LCA, cleaning and degreasing agents, metal industry; metal industry, cleaning and degreasing agents, LCA; rapeseed methyl esters, cleaning and degreasing agents, metal industry, LCA; vegetable oils, ethylhexyl laurate, cleaning and degreasing agents, metal industry, LCA

1 Introduction

Due to their negative effects on the (working) environment, most European countries have formulated a policy to reduce the emission of solvents to the air. One of the possibilities to reduce the emissions is the substitution of the solvents by non or less volatile products. An example can be found in the sheetfed offset printing in which solvents used as manual cleaning agents can be successfully substituted by vegetable oils and their fatty acid esters (VOFA) [1]. These products are non-volatile and partly derived from renewable resources. An EC-founded project has been carried out to further examine the technical possibilities and environmental benefits of VOFA as cleaning and degreasing agents in the metal industry [2]. Part of this EC project consisted of

an environmentally orientated Life Cycle Assessment (LCA) of two VOFA products and one solvent product. The results of this LCA will be presented in this article. The full results of this study are described in TERWOERT et al. [3].

2 Materials and Methods

The LCA was carried out according to the guidelines of the SETAC [4]. For more detailed choices concerning the characterisation in the LCA, the methodology of HEIJUNGS et al. [5] was used. For the characterisation on the use of land, the methodology of FRISCHKNECHT [6] was used, because this aspect has not been elaborated thoroughly in the methodology of HEIJUNGS. For estimates concerning emissions of fertilisers and pesticides during use, the methodology of WEGENER SLEESWIJK et al. [7] and ZEIJTS et al. [8] was used. Calculations were carried out with the computer program Simapro 3 [9]. Inventory data were mainly based on data from existing studies [10-14].

2.1 Products examined

On the basis of previous experience with VOFA products in the printing industry, two VOFA products were chosen and compared with one solvent product (VOC) used nowadays for cleaning and degreasing activities in the metal industry:

- 100% rapeseed methyl ester (RME)
- 100% coconut oil based ethylhexyl laurate (EHL)
- 100% mixture of mineral oil based dearomatised C10-12 hydrocarbons (VOC)

2.2 Functional unit

Due to the lack of practical experience with the use of VOFA as cleaning agent in the metal industry, no functional unit could be established. From experience in the offset printing industry it may however be expected that the amount of VOFA used will only be 25% of the amount of VOC used [1]. This is caused by the lack of any loss of product due to

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evaporation and the good solvency power of the VOFA products. For the metal industry, no differences in cleaning efficiency for these products are to be expected compared to the printing industry. Therefore these amounts could also be realistic in the metal industry. However, for this study, a conservative estimation was made and the comparison was based on 1000 kg of each product used. A sensitivity analysis was carried out in which the comparison was based on the amounts used in the printing industry.

Based on estimations in the Netherlands [15], the emission factors to air during use within an open cleaning system were established at 25% for VOC and 0% for VOFA.

2.3 System boundaries

The life cycles examined are depicted in Figure 1. As can be seen from this figure, the study does not include the waste treatment of the cleaning agents. Although this part of the life cycle is not expected to be unimportant, too little practical experience exists to make a quantitative comparison possible. Furthermore, packaging and cleaning devices were not incorporated in the study.

The environmental interventions for all production processes were based on European averages, except for the cultivation of the crop. For coconut oil (including extraction of the oil),

the cultivation was based on the Philippines in which 90% of the coconut oil used for European oleochemicals is produced. For rapeseed oil, the cultivation was based on France and Germany which represent $\pm 70\%$ of rapeseed cultivation in Europe.

The production of capital goods was not included, except for the generation of energy for which data from ETH [6] were used in which the production of capital goods is included. The production of capital goods, can make up 10% of the classification scores within the generation of electricity.

Allocation was based on the mass of the products, except for the extraction of the vegetable oils for which allocation was based on the economic value of the products. This exception was made because otherwise the major part of the environmental impacts would be allocated to the by-product (e.g. rapeseed meal).

Fixation of carbon dioxide by crops as well as release of carbon dioxide from burning or degradation of the crops was left out of the calculation.

3 Results

The results of the inventory as well as the characterisation will be presented.

Production of cleaning agents

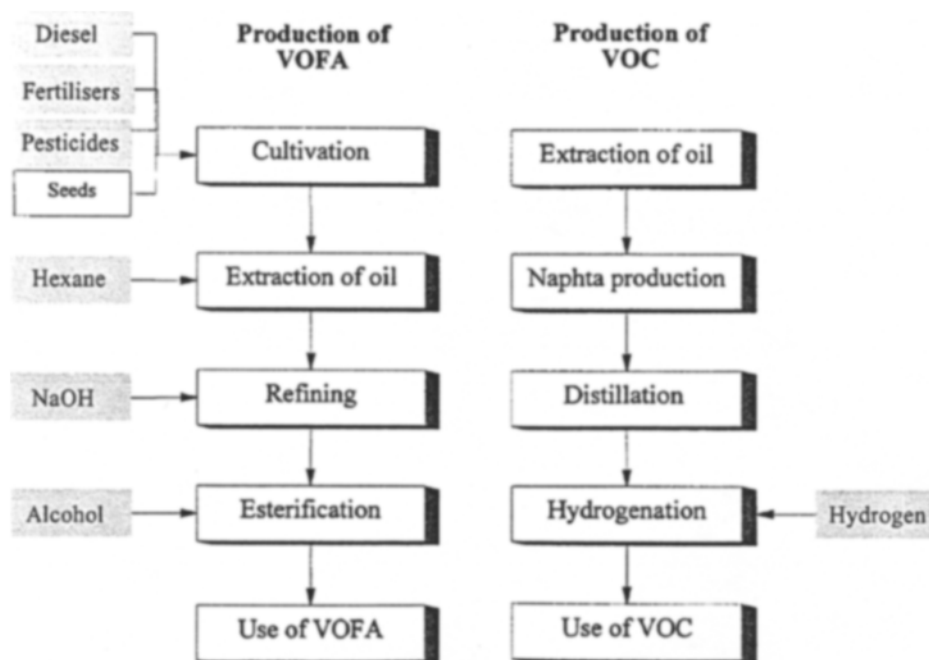


Fig. 1: Life cycles of examined products. Shaded areas indicate the chemicals of which the production was included in the study

3.1 Inventory

(1) Energy

Total energy demand is presented in Table 1. The energy content of the biomass was left out of the calculation. The energy content in Table 1 refers to the energy content of the non-renewable resources. From Table 1, it can be seen that the production of VOC requires most energy, followed by the production of EHL and the production of RME. The total energy demand is mainly related to the energy content of the material resources of the product (in the case of EHL and VOC) and to the process energy (in the case of RME). Transport energy only has a negligible contribution. Focusing on the process energy, differences between the three types of products are less pronounced. The production of RME has a relatively high energy demand due to the extensive use of N-fertiliser during rapeseed cultivation. The production of N-fertiliser is very energy intensive.

(2) Emissions to air

The main emissions to air (> 0.1 kg/1000 kg product) are listed in Table 2. For RME, diesel combustion during tillage of the agricultural land forms the major contribution to emissions of CO, NO_x, and C_xH_y, whereas the production of the various fertilisers (N, P, CaO and MgO) forms the major contribution to emissions of CO₂, NO_x, SO_x, dust, methane and fluorine. The use of the N-fertiliser gives a major contribution to emissions of ammonia and N₂O.

For EHL, the main emissions to air are related to the production of 2-ethylhexanol and the combustion of diesel dur-

ing bulk transport of the coconut oil. An exception is the emission of dust, for which the cultivation and extraction of the coconuts is mainly responsible.

For RME as well as for EHL, the emission of hexane is solely related to the extraction of the oil. The high score for EHL is related to the high hexane losses at production plants in the Philippines compared to Europe (3.2 kg versus 0.53 kg per 1000 kg of extracted oil).

For the solvent product, the main emissions (CO₂, CO, NO_x, SO_x, dust) are related to the production of hydrogen (necessary for the hydrogenation of the solvent) and the production of naphtha from oil. An exception is the emission of C_xH_y, which is almost entirely related to the emission of VOC during use.

(3) Emissions to water

The main emissions to water (> 0.1 kg/1000 kg product) are listed in Table 3. For RME, many emissions to water (P_{tot}, C_xH_y, crude oil, fatty acids, fluorine and sulphates) are related to the production of the P-fertiliser, whereas the emission of ammonia is mainly related to the production of the N-fertiliser. Leaching of fertilisers during cultivation of the seeds forms the largest contribution to the emission of phosphate and nitrate.

For EHL, only the emissions of COD, N, solids, acid and Fe seem to be important. These emissions are mainly related to the discharge of the coconut water when the coconuts are halved.

Table 1: Energy profile of examined products

Type of energy → Product ↓	Process energy		Transport energy		Energy of material resource		Total	
	(MJ)	(%)	(MJ)	(%)	(MJ)	(%)	(MJ)	(%)
RME	6107	65	247	3	2990	32	9344	100
EHL	5097	20	281	1	20155	79	25533	100
VOC	9223	15	"	"	50809	85	60032	100

¹⁾ For VOC, the transport energy is included in the process energy

Table 2: Main emissions to air (kg/1000 kg)

Product ↓	CO ₂	CO	NO _x	SO _x	C _x H _y	CH ₄	hexane	dust	NH ₃	N ₂ O	F
RME	920	1.8	5.3	1.6	0.3	0.5	0.3	21.0	0.9	1.1	8.5
EHL	358	0.3	3.1	2.7	2.5	≈0	1.8	0.8	0	≈0	0
VOC	1130	1.2	4.9	3.9	255.6	0	0	0.5	0	0	0

Table 3: Main emissions to water (kg/1000 kg)

Product ↓	COD	N _{tot}	P _{tot}	C _x H _y	NH ₃	solids	crude oil	F	SO ₄ ²⁻	fatty acid	Al	Fe
RME	5.8	43.2	1.6	0.2	7.3	0.9	0.4	5.1	89.6	0.6	0.2	0
EHL	8.0	2.5	≈0	0.6	0	24.1	≈0	≈0	0.1	0	≈0	2.5
VOC	≈0	≈0	≈0	≈0	0	0.7	≈0	0	0	0	0	0

For VOC, emissions to water seem to be very small compared to VOFA.

(4) Emissions to soil

Emissions to soil are not listed separately because they are solely related to the use of pesticides during rapeseed cultivation. Whereas other industrial processes will also lead to emission to soil (e.g. by spillage), no data about these emissions were known.

(5) Solid waste

In Table 4 all kinds of solid waste (e.g. coconut shells, ashes) are summed on a weight basis. The production of solid waste is mainly related to the waste produced during coal mining for the production of electrical energy. This is most extensive during the production of RME, due to extraction and refining of the oil and the production of N-fertiliser. The relatively high score for EHL consists of waste from those coconut shells and husks not used as fuel or for improvement of the soil.

Table 4: Production of solid waste (kg/1000 kg)

Product ↓	Final waste
RME	22.6
EHL	13.6
VOC	3.8

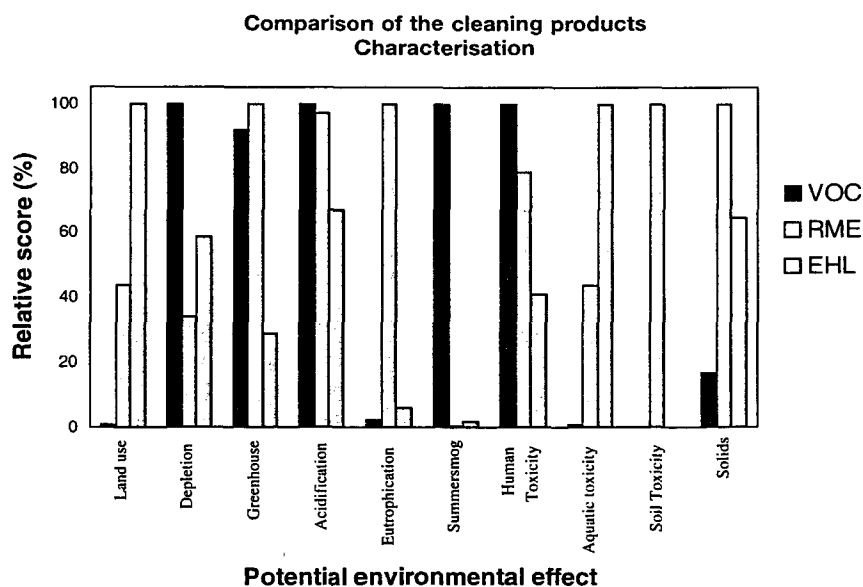
3.2 Characterisation

The results of the characterisation are shown in Figure 2. On the basis of 1000 kg of used product, both VOFA are environmentally more favourable on the aspects of depletion of abiotic resources, formation of summer smog and human toxicity. However, they are less favourable on the aspects of land use, eutrophication, aquatic toxicity and solid waste. For the greenhouse effect and acidification, only EHL is more favourable whereas RME has nearly the same score as VOC. For soil toxicity, only RME has a score.

Concerning land use, agricultural production clearly needs a much bigger area than industrial production. Besides it could be deduced that rapeseed cultivation is more intensive than coconut cultivation.

For depletion of abiotic resources, differences are mainly caused by the use of renewable resources for VOFA. However, differences between VOC and VOFA are not as large as one might expect. This is partly due to the alcohol part of VOFA which is derived from non renewable resources (in the case of EHL, the weight fraction of the alcohol in the ester equals 50%) but also due to energy use during VOFA production.

The greenhouse effect is mainly related to emissions of CO₂ during production of steam for various processes and combustion of diesel for land tillage (RME) and bulk transport



Landuse: Use of land (ha.year), Depletion: depletion of abiotic resources (kg), Greenhouse: greenhouse effect (kg CO₂-eq.), Acidification: acidification (kg SO₂-eq.), Eutrophication: eutrophication (kg PO₄³⁻-eq.), Summer smog: formation of summer smog (kg C₂H₄-eq.), Human Toxicity: human toxicity (kg BW), Aquatic Toxicity: toxicity to aquatic organisms (m³ water), Soil Toxicity: toxicity to soil organisms (kg soil), Solids: total final waste (kg)

Fig 2: Characterisation of the used cleaning products

(EHL). However, in the case of RME, the emissions of N_2O during cultivation also form an important contribution (25%).

Acidification is mainly related to emissions from NO_x and SO_x during combustion of diesel for land tillage (RME) and bulk transport (EHL) and of fossil fuels during all production steps (VOC). The score for EHL is debatable because a large part of the emissions of NO_x and SO_x during bulk transport will not contribute to acidification on land [16]. In fact, if the estimation is made that only 10% of the emissions at sea will be deposited in an area sensitive to acidification [16], the score of EHL on acidification would be lowered with $\pm 40\%$. The relatively high score for RME is mainly related to the emission of ammonia during production and use of N-fertiliser.

The high score of RME for eutrophication is related to the emissions of ammonia and phosphate during use of the fertilisers. The major part of the score for EHL is debatable because it originates from the discharge of coconut water in the Philippines. Here eutrophication is not such a large problem as in Western Europe.

The evaporation of VOC during use contributes to the formation of summer smog, as this is mainly related to the emissions of C_xH_y to the atmosphere.

As is frequently the case within LCA's, an important part of the score for human toxicity is related to emissions of SO_x and NO_x during combustion processes. However, for the solvent product the emission of VOC during use also forms an important contribution, whereas for the RME product, an important contribution can be related to a single fluorine emission during the production of the P-fertiliser.

The high score for EHL on aquatic toxicity is almost entirely related to a single emission of the very toxic phenol during propene production (necessary for the production of 2-ethylhexanol). Emissions during P-fertiliser production contribute the major part to the score for RME. The production of VOC is accompanied by emissions of low aquatic toxicity.

A score for soil toxicity is only given for the RME product, as emissions (of pesticides) to soil are only relevant during the cultivation of rapeseed.

Within the score for solid waste, no relation could be made with the type of waste and inventory data could only be summed on weight basis. Therefore, the relation of the scores with the production processes is identical to the inventory.

4 Discussion

From the inventory and characterisation, it can be seen that the tillage of the land and the use of fertilisers form impor-

tant contributions to the total environmental profile of RME. However, differences between the inventory and characterisation can also be seen. For example, the emission of phenol during EHL production is only very small but forms almost the entire contribution to the effect of aquatic toxicity. From the characterisation it can also be seen that for aspects of acidification and eutrophication, a large part of the emissions do not contribute to those effects at the place of deposition. For those effects, a more spatial differentiated approach would be desirable.

In order to have a well-considered view on the environmental effects of VOFA and VOC, a specific cleaning task needs to be defined and the amounts of VOFA (and VOC) required need to be determined, together with the relevant waste treatment scenario. Possibilities for the recycling of VOFA, already available to a limited extent, may have a decisive impact on the environmental balance.

However, to value the sensitivity of the results, a sensitivity analyses was carried out in which the amount of VOFA used was lowered to 25% of the amount of VOC used. These amounts represents the actual situation in the printing industry due to the high solvency power of the VOFA and no loss of product due to evaporation. As no differences with the metal industry are to be expected, these amounts are expected to be realistic for the metal industry. Compared to the starting situation (\rightarrow Fig. 2), the results of this sensitivity analysis show that now both VOFA also score considerably more favourably on the greenhouse effect and acidification whereas EHL also scores more favourably on solid waste, compared to VOC. The only impacts on which VOFA continue to score unfavourably are land use, aquatic toxicity and (for RME) eutrophication. However, the occupational health of the workers, one of the main motives to substitute VOC, is not included in the current LCA methodology while it may have a decisive influence on the weighing of the use of VOC against VOFA.

To improve the life cycle of VOFA, several options can be considered. For EHL, improvement options can be found in the utilisation of the coconut water which now flows freely to the surrounding surface water, by sun drying of the coconut meat (to diminish emissions to the air), by utilisation of the shells and husks to diminish the solid waste produced, by diminishing the hexane losses during extraction, and by reducing the phenol emission during 2-ethylhexanol production. For RME, improvements are possible in the use of fertilisers. The use of manure instead of artificial fertiliser may cause an important reduction in the scores for a number of aspects (depletion of abiotic resources, human and aquatic toxicity and solid waste). However, the contribution to the global warming effect and to acidification will be enlarged due to the higher evaporation of N_2O and ammonia during use. Improvements can be made by an optimisation of the use of N-fertiliser from 169 kg/ha (with a yield of 3.2 ton/ha) to 120 kg N/ha (with a yield of 3.0 ton/ha) and through the possibilities of plant breeding techniques with which a yield

of 5.8 ton/ha [17] would be possible, using the same amount of fertiliser.

5 Conclusions

From the present study it can be seen that the environmental favourability of products derived from vegetable oils compared to solvent products is strongly dependent upon the amounts needed for the task to perform. If the functional unit is based on experiences with VOFA in the printing industry (25% of VOFA used compared to VOC used), the VOFA products are more favourable on a large number of aspects. For some aspects, however, (land use, aquatic toxicity and eutrophication) VOFA continue to score unfavourable. For these aspects, optimisation of the cultivation of the crops and the production of fertilisers seems to be necessary.

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